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ABSTRACT

This teaching guide provides background information, instructions, and copies of sample cards needed for an image walk, a series of demonstrations and activities that reveal the images carried by sunlight. The three cards are used: (1) to demonstrate that sunlight passing through holes of any shape create round spots of light--images of the sun; (2) to reflect sunlight and make images of the sun, and to demonstrate that a large square hole acts like a collection of small holes; and (3) to study the array of images that result from an array of holes. The cards, originally printed on cardboard, include outlined areas indicating punchouts needed to accomplish the demonstration activities. Also provided are activities which extend the image walk, continuing the process of discovery using pinhole viewers and a slide projector. (JN)

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IDEAS INSCIENCE

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Notes for Teachers

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Light & Images

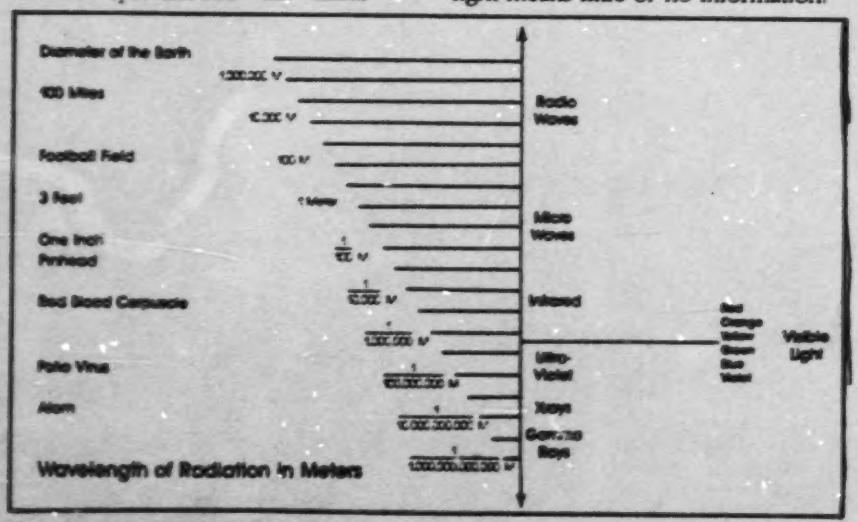
You can be light-hearted, light-headed, light-fingered, or light on your feet. You can make light of things, bring secrets to light, or hide your light under a bushel. You can be quick as a flash, moving at lightning speed. You can seek the bright lights or trip the light fantastic. You can see the light and achieve enlightenment—or you can be completely in the dark.

Light—the stuff that's shining on this page as you read—is a much used metaphor and a puzzling sort of thing. What is light? And what is it about the light shining on this page that lets you read the text?

The first definition that the dictionary gives is: light is "something that makes things visible or affords illumination," a vague and unsatisfying definition that circles around like a dog chasing its own tail. Physicists define light as electromagnetic radiation—a traveling energy wave produced by a vibrating electric charge. Because light has the properties of a wave, we can talk about its wavelength and frequency. The light that our eyes can see—the visible spectrum—is a narrow band of wavelengths in the electromagnetic spectrum, which also includes radio waves, x-rays, ultraviolet light, and infrared radiation.

Light and other electromagnetic radiation moves fast, speeding along at 186,282 miles per second, much too fast for you to perceive its movement. Since you can't see light move, thinking of it as a moving wave can be a little difficult. And though thinking about light as a wave is very useful for some purposes, it's not very helpful if you just want to know why you can't read in the dark.

In this booklet, we hope to shed new light on the subject of light. We'll start with a definition that you will not find in the dictionary: light is information. This information is rushing past at 186,282 miles per second, ricocheting off the walls, bouncing around like mad, and, sometimes, hitting you squarely in the eye. When you take away light you take away information. In a darkened room, you can see little or nothing of your surroundings. Little or no light means little or no information.



Electromagnetic spectrum
Visible light is only a narrow band of wavelengths in the electromagnetic spectrum.

Consider a photographer taking a color photo of your class. With a camera, film, and a little bit of light, the photographer can take a snapshot that contains a great deal of information: you can look at the picture and count the students or determine what color shirt you wore that day. Where did this information come from? It wasn't on the film or in the camera. The information was in the light.

The dictionary defines an image as "a physical representation of a person, animal, or thing, photographed, painted, sculptured, or otherwise produced." The photograph of your class is a static image containing much of the information carried by the light. Whenever you look at your surroundings, you gather visual images—the light entering each eye makes an image on your eye's retina. Even though you can't see light move, you can directly experience the images it produces.

Rather than defining light as information, we could say that light is images. You may prefer to say that light carries information and makes images, but whichever phrasing you choose it's clear that light, information, and images all go together.

This issue of *Ideas in Science* will introduce you to activities that reveal the images carried by light, letting you experience light in a new way. You may not come away from this packet with a succinct verbal definition of light and images, but you should gain an understanding of light and become more aware of the images all around you: your reflection in a mirror, the enlarged image you see through a microscope or a telescope, the multiple images that you see when the moon reflects on rippling water. We hope that these activities will help you find a new way of looking at light—a new way of seeing the world around you. ○

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The Light Artist and the Process of Discovery

Science begins with curiosity and observation—noticing a natural phenomenon and attempting to account for it. Imagine, for a moment, that you are standing in the shade beneath a tree on a sunny day. The leaves of the tree block most of the light, but gaps between the leaves let some sunshine through. If you look up into the tree, you can see that the gaps between the leaves are all different shapes and sizes. But if you look down at the ground, you see round spots of light, not the irregularly shaped spots that you might expect.

Here at the Exploratorium, San Francisco's museum of science, art, and human perception, an artist named Bob Miller noticed the round spots of sunlight in the shade of a tree. Bob Miller had long been preoccupied with the properties of light and had made use of these properties in a number of artworks. He knew why the spots of sunlight were round: each spot of light was an image of the sun, isolated from the sunlight by the gaps between the leaves. (For a detailed explanation, see page 6.) Intrigued by the artistic possibilities of these sun images, Bob Miller began experimenting with light and images: checking to see whether holes of different shapes and sizes would always make round images, using an array of holes to make multiple images, reflecting images with mirrors, bending light and images with lenses and prisms—in short, trying to get a better understanding of light and images. Over the past twelve years, Bob Miller developed some unconventional ideas about light. You have already read two of his ideas in the introduction: "Light is information," and "Light is images."

"I used to think of diffuse white light as uninteresting," he says. "But the white light shining on a white piece of posterboard in one spot is very different from the light on the same posterboard if you move it to a spot a few feet away. And there's a tremendous amount of information in the light that's incident on both boards."

Thinking about light led Bob Miller to think about how we perceive light. You may think that you see the outside world when you look out your schoolroom window on a sunny day. Bob would disagree. "You see *light*," he says. "It's the only thing you *can* see, the only thing your eye can detect. And light is invisible unless it gets into your eye."

At the Exploratorium, Bob Miller showed his discoveries to friends in a set of demonstrations that has become an Exploratorium tradition known as Bob's Image Walk. The activities described in this booklet will allow you to duplicate Bob Miller's demonstrations with your class.

The Image Walk is a process of discovery, a series of experimental steps that led Bob Miller to an intuitive understanding of light and images. Duplicating this process with your class can encourage and enable your students to experiment and discover for themselves, and at the same time teach them about light and images, information fundamental to understanding how they perceive the world.

This booklet also includes activities that will allow you to extend the Image Walk, continuing the process of discovery using pinhole viewers and a common piece of classroom equipment: your slide projector.

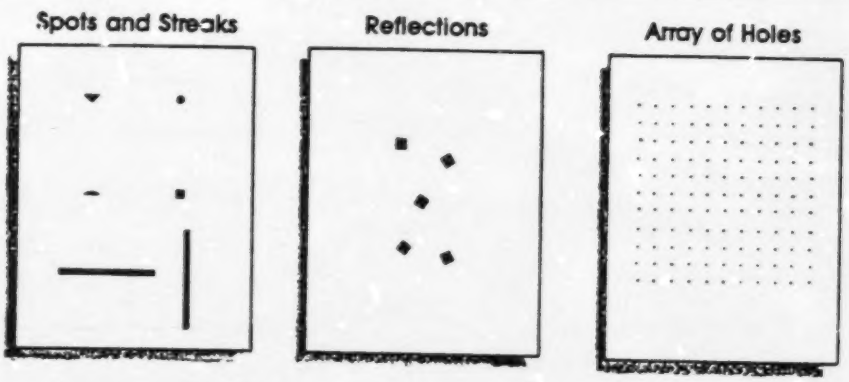
This booklet, like Bob's Image Walk, is intended to encourage you to become aware of the observed, but often unnoticed, characteristics of light and images. ○

PREPARATIONS FOR AN IMAGE WALK

To take an Image Walk, you will need the three *Doing Science* cardboard filters included in this packet: *#1—Spots and Streaks*, *#2—Reflections*, and *#3—Array of Holes*. If these have been separated from the packet, you can duplicate them. You will need a single-edged razor blade or an exacto knife and three sheets of non-corrugated cardboard or posterboard measuring 8½" by 11" or larger.

Spots and Streaks:

In one sheet of cardboard, cut a round hole measuring ¼" in diameter, a square hole measuring ¼" by ¼", a triangular hole measuring ¼" on a side, and a crescent-shaped hole with an arc measuring ⅝" in length. Below these holes, cut two rectangular holes measuring ¼" by 2".



Reflections:

In one sheet of cardboard, cut four square holes measuring ⅜" by ⅜". Arrange them within a 3" by 5" area.

Array of Holes:

In one sheet of cardboard, cut a regular array of square holes measuring ¼" by ¼", ¾" apart. Making this card requires a great deal of patience. If you find cutting so many holes tedious, you can replace this sheet with a sheet of pegboard.

You can improve the images you make by blocking as much of the surrounding light as possible. You may want to cut a hole (measuring 7¼" by 10") in a large sheet of cardboard or posterboard and mount your *Doing Science* sheets in this hole with tape.

At some point during your walk, you may need to hold the *Doing Science* card high in the air. To make this easier, you may want to attach to the cardboard a stick that you can use as a handle.

Other materials:

You will also need a sheet of stiff white posterboard that you can use as a screen to reflect the images to your eye, and a mirror measuring at least 3" by 5". ○

Image Walk:

Step by Step

The following steps will lead you through Bob Miller's Image Walk. Included with our step-by-step instructions are quotes from Bob Miller that convey some of the spirit of inquiry inherent in the process.

Throughout the Image Walk, Bob Miller refers to the round spots of light created when the sun shines through a hole as "images of the sun." On page 6, we explain in detail how a light shining through a hole can create an image of the light source. But before you read the explanation, we suggest you go on an Image Walk.

For an Image Walk, you'll need a sunny day. You can take your class outdoors, or use the sunlight that shines in your classroom window—as long as it is direct sunlight. You will also need the *Doing Science* cards described on page 1. If you do the Image Walk outdoors, choose a patch of direct sunlight that is near a shady area. If you work in the middle of a sunny playground, the brightness of your surroundings will make your images more difficult to see.

We suggest you do the Image Walk in the morning or the afternoon. When the sun is directly overhead, you may have a hard time holding the filter far enough from the screen to make a good image. At any time of day, you'll need a helper to hold the screen while you hold the filter.

To avoid producing a distorted image of the sun, you must correctly position your filter (the *Doing Science* cards or your hands) and your screen (the white posterboard). Always hold the filter perpendicular to the sun's rays; always hold the screen parallel to the filter. ○

Step 1:

Start under a shade tree, where just a little sunlight leaks between the leaves. Look up at the tree, and notice that the gaps between the leaves are all shapes and sizes. Look at the ground and notice the rounded uniform spots of light. At noon, the spots will be close to round, though some spots may overlap. If the sun is not directly overhead, the light strikes the ground at an angle and the round spots are distorted to make ovals. If you hold your white posterboard screen so that its surface is perpendicular to the sun's rays, the light will make round spots. Why does sunlight shining through irregular holes make such round spots of light?

Bob Miller always begins his Image Walk under a shade tree, saying: "It begins here, with a commonly observed and reported phenomenon: the light coming through the cracks between the leaves in the trees hits the ground or a piece of white cardboard and is round. Now you can look up and see that the spaces between the leaves aren't round. They're all irregular. The round spots of light are images of the sun."

Step 2:

Make your hand into a fist, leaving a small gap in the curl of your fingers, and hold your fist so that the sun shines through the gap onto your posterboard screen, held about 6 feet from your hand. Cross the fingers of one hand over the fingers of the other to make an array of small holes and an array of spots.

"If I cross the fingers of my hands, I can make a whole bunch of sun images with the light coming through the holes. Now if I take my hands away, light that was coming through the holes in my fingers is still passing through there. When I put my hands there, then you can see that the images are really there. But you can say in a sense that they are always potentially there. That the information is always there."

"Once you start noticing these images, you'll find them all over the place. You can make a hole with your hand, and there is the hole in my hand making an image of the sun."

Step 3:

Hold the Spots and Streaks card about a foot away from the posterboard screen and let sunlight shine through the holes. At this distance, the spots of light will be the shape of the holes in the card. Gradually move the card away from the screen and notice that the spots of light become more rounded. When the card is about 6 feet from the screen, the spots will be round. Continue to move the card away from the screen, and notice that the spots remain round—but get larger and larger.

Step 4:

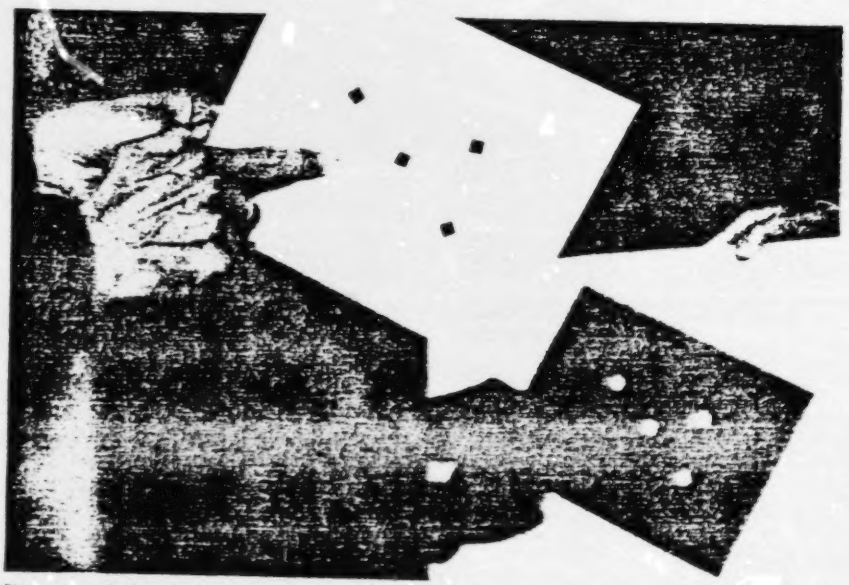
Hold the Spots and Streaks card so that the sun shines through the slits and makes long streaks on the posterboard screen. Even though the ends of the slits are square, the streaks of light will have rounded ends. Use your fingers to divide one of the slits into smaller holes. Each small hole will give you a round spot. The streak of light is a collection of round spots, lined up side by side.

Step 5:

Hold the Reflections card about 3 feet from the screen and cover most of the square hole with your finger, letting the light pass through just one corner of the hole to make a round spot on the screen. Move your finger to let light pass through another corner of the square hole (see photo). Light passing through the two corners makes two round images on your posterboard. Each part of the square hole lets through another round image. You could think of the square hole as a collection of lots of little holes. On the screen, the centers of the two images are separated by the distance between the two uncovered corners. Move the card away from the screen and notice that the images get larger and eventually start to overlap. If you were to move back far enough, the images would get so large that they would overlap almost completely.

"Instead of using the holes in between the leaves, we can use the holes in a board, a little square hole, a triangular hole, and a very irregular hole. And if I hold that board up sort of perpendicular to the sun—no matter what the shape of the hole—I still get a round image of the sun. And it doesn't matter if it's a small hole or a bigger hole—all the images are the same size. And as you move back, they all get larger. The image gets bigger the farther back you move, but it also gets dimmer."

With the slits in the same board, Bob Miller demonstrates that a streak of light is made up of many round images. "As I pull the card back further, the streaks of light get bigger and bigger. But if I block the slit off with my fingers, you can see that each streak is just a row of images of the sun that are all lined up."

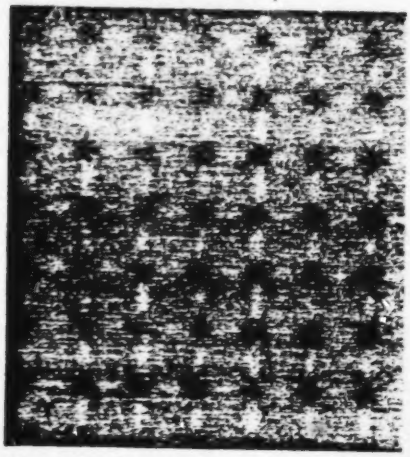


"You can take just this little tiny corner of the square hole and make a little tiny image of the sun coming through that corner. Now about a quarter of an inch away, there's another tiny image coming through the other corner. So now there's an image there and an image there, about a quarter of an inch apart. But now as I pull back, both images get bigger and bigger. But their centers are no farther apart than that quarter of an inch. So by the time the images have gotten real big, the centers are in effectively the same place. So you have a single large image of the sun with a quarter-inch fuzzy edge."

"I had always thought that you could only get an image with a little tiny hole. It turns out that you can have any size aperture, and any shape. As long as you get back far enough with the screen, the light will resolve itself into just about as sharp an image of the sun as you get with a little hole held close to the screen."

Step 6:

Hold the Array of Holes card so that the sun shines through the holes onto the posterboard screen. Start with the screen about a foot away from the card, and slowly increase the distance between the card and the screen. As you increase the distance, the spots of light on the screen will become rounded, grow larger, and gradually begin to overlap.

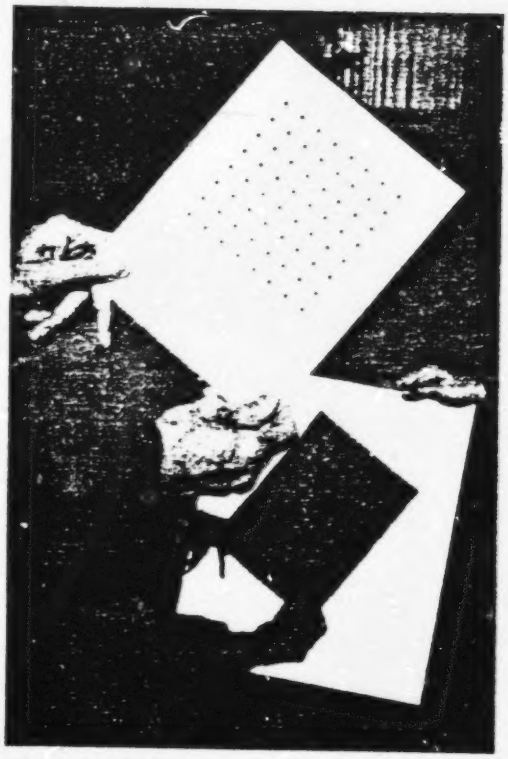


"Some of the images are dimmer than others. That just means that a hole is smaller and it lets less light through. Sometimes you see a really bright one, and that means the hole is bigger."

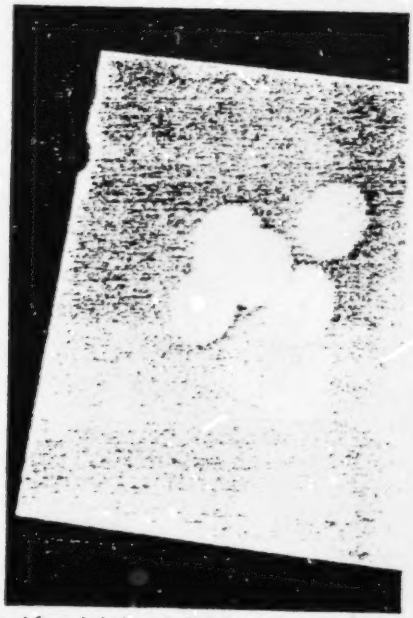
Step 7:

Hold the Reflections card up and let sunlight shine through the holes to make round spots on the posterboard screen, held about 9 feet away. As you have come to expect, square holes make round spots of light. Now, hold or tape a mirror to the back of the Reflections card so that each square hole will act as a square mirror. Have a helper hold the posterboard screen in a spot of shade about 20 feet from you and use the mirrors to reflect the sunlight onto the screen. It may take you a few tries to hit the screen with the spots of reflected light, but when you do, you will see that the spots of reflected light are round images of the sun. Since you have separated the filter (your Reflections card) from the screen by a great distance, the round images are very large.

Through all his experiments, Bob Miller came to the realization that the image of the sun is in the light. Light carries information—and where the light goes, the information goes, too. "A mirror is really a reflecting pinhole. A mirror just reflects the light that would go through the hole. So by putting square mirrors here instead of square holes, I get a reflection of the image that would go through the holes."



When Bob Miller experimented with a pegboard, he realized that he could think of ordinary sunlight as overlapping images. "If we tip a pegboard full of holes up so it's pretty perpendicular to the sun, it makes a whole bunch of sun images. And as I start to back up, they get bigger and bigger. If I drilled still another hole in the board, it would let still another image through. So I could keep drilling holes, and every time I drilled a hole I'd let an image through. In fact, I could drill so many holes that I'd drill the whole board away. And then I'd have what I used to think of as uninteresting diffuse white light. But there's a tremendous amount of information in that light."



Usually, people who experiment with the images filtered from light by a hole talk about "pinhole images," implying that only a very small hole can make an image. Experimenting with mirrors made Bob Miller realize that he could use any size hole, as long as he set the screen far enough away from the hole. He remembers using a large rectangular mirror to reflect sunlight to a faraway wall. "I guess I expected to see a nice rectangular spot of sunlight over there. Well, I didn't. It was quite rounded. The fog was coming in that day, and the whole wall was filled with an image of the sky. You could see the slightly out-of-shape bright spot of light that was an image of the sun, and then you could see the fog going by. Here was a 30 by 40 inch mirror. Now that's certainly not a pinhole, but over there on the wall 130 feet away, the resolution became so good that you could actually recognize the sun and the clouds and the fog going by. I realized that the aperture size was just about limitless."

Step 8:

You can use your filters to make images that include more than just the sun. Find the fuzzy shadow cast by something high above you, such as a tree branch or a telephone wire far overhead. Use the hole you can make with your fist to make an image on the posterboard screen, taking care that part of the shadow falls on your hand. The round spot of light on the screen will include an image of the branch that is casting the shadow. If you don't have a good image of the branch, move your hand around the shadow until you can see an image of the branch crossing the sun. Notice that the image of the branch is upside-down and left and right are reversed. The image of the sun was also upside-down and reversed, but you didn't notice, since an inverted and reversed circle can't be distinguished from the original shape.

"Now I'll move over here into this fuzzy shadow and I'll make an image of the sun with my hand again. Now you can see an image of the sun with an image of the tree in front of it. You can see the silhouette of the branches in front of the sun. Of course, it's upside down—and also left-right reversed."

Step 9:

Hold your Array of Holes card where the fuzzy shadow falls across it. Hold the posterboard screen so that you can see the images. Notice that each image is a little different. Each hole lets through a different part of the light and gives a slightly different image. (The poster accompanying this *Ideas in Science* shows a similar array of images produced using a slide projector as a light source.)

"You can see that through every hole is a different image. Every hole is a slightly different viewpoint. From image to image the changes are very slight, but from the right-hand side of the board to the left-hand side of the board, the images are very different. In fact, you can't see much similarity between what's on the right-hand side of the board and what's on the left-hand side of the board."

Images Of The Sun

Bob Miller begins his Image Walk under a tree where the sunlight makes round spots of light on the ground. A glance up at the leaves of the tree shows that the gaps between the leaves aren't round. Yet sunlight passing through these gaps makes round spots.

You might think that sunlight shining through a square hole would make a square spot of light. If you follow the Image Walk from start to finish, you'll find that the shape of the spot of light matches the shape of the hole only in a very narrow range of conditions. If you hold your Spots and Streaks card about a foot from a piece of white posterboard and let the sun shine through the square hole, the spot of light on the posterboard will be square. But as you gradually increase the distance between the posterboard and the hole, the spot of light on the posterboard changes, becoming more and more rounded. When the hole is about 6 feet from the posterboard, the spot of light is round. At distances of 6 feet or more, the spots of light made by sunlight shining through the square hole, through the triangular hole, through the jagged edged hole are all round and all the same size, regardless of the size of the hole.

To produce these round spots of light, you need three things: sunlight, a hole, and a piece of white posterboard. You could think of each of these things in a more general way. The sun is a light source; the hole is a filter that allows just a little light through and blocks the rest; and the posterboard is a screen, serving only to reflect light to your eyes just as a movie screen reflects light from a projector to your eyes.

On the Image Walk, you used a variety of filters, ranging from the gaps between leaves to the holes you can make with your own hands. You can use different screens: the spots are round whether they shine on the posterboard, your hand, or the ground. The one thing that you do not change throughout the outdoor section of the Image Walk is your light source: the sun.

At the very beginning of the walk, Bob Miller calls these spots of light "images of the sun" and says that they are round because the source of light, the sun, is round. If the light source were not round—if it were square or triangular—then you would see a square or triangular image on your screen. You can confirm this by using one of your filters with a different light source. If you shine the light of the slide projector through a hole as we describe on page 10, you find an image of the filament of the light bulb in the projector. You can also get a sharp image using a 200-watt bulb, a candleflame, or just about any light source in a darkened room. (See Figure 1.) The shape and color of the image will match the shape and color of the light source, and the brightness of the image will vary with the brightness of the light source.

The image formed by light shining through a hole depends on three characteristics of the light: its frequency or color, its direction, and its intensity or brightness. These characteristics, in turn, depend on the light source. Sunlight, for instance, contains many frequencies, including light in all colors of the rainbow and frequencies both above and below the visible spectrum. The light radiates in all directions from the sun, and its intensity varies with the atmospheric conditions and the time of the year.

If an image of the sun depends only on these three characteristics of the light, then why can't you see the sun's image just by holding a white piece of posterboard in the sunlight? If the light is shining on the posterboard, there should be an image of the sun. That's true: there is an image of the sun on the white posterboard. There are many images of the sun, carried by the light radiating in all directions from the many points on the sun. There are also other images: some of the light on the board is reflected light, bouncing off the clouds, the trees, the buildings, and other objects, and this light carries images of the clouds, the trees, and the buildings. The resulting jumble of light is a mixture of many frequencies, directions, and intensities. You can't see an image of the sun on your posterboard, but the problem is not the lack of an image. There are so many overlapping images that you can't see one amid the jumble. (See Figure 2.) To see a single image, you must isolate a small part of the light.

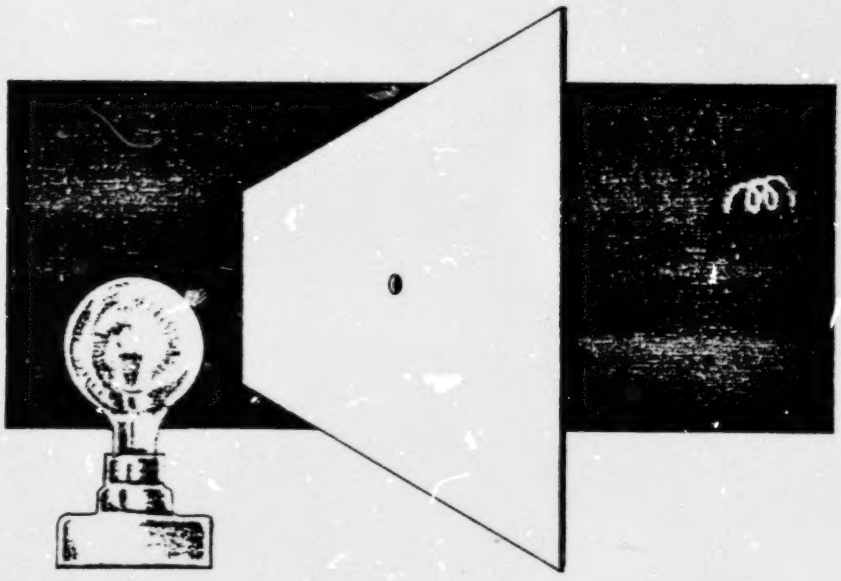


Figure 1
Using a hole as a filter, you can make an image of any bright light source. You can get started with a 200-watt bulb and a hole that is ¼ inch in diameter. The image will be clear if you place the screen about 3 feet from the filter. Try this in a dark room, so that ambient light does not obscure your image.

You could compare the sunlight on the white posterboard to the radio waves picked up by a transistor radio. The radio receives radio waves of many frequencies, and the waves carry the information being broadcast on all stations: news, music, commercials. To hear one station, you tune your radio to that station alone. To see the image of the sun, you must "tune in" one image and filter out the rest.

Figure 2
When you hold a white piece of posterboard in the sunlight, the image of the sun is lost in a jumble of other overlapping images.

Textbooks usually refer to "light rays." There really is no such thing as a ray, an infinitely thin beam of light. But thinking about light in terms of rays makes understanding it much easier. Figure 3 shows some light rays radiating from the sun and encountering a piece of cardboard pierced by a hole. You can see that only a few of the light rays radiating from each point on the sun can pass through the hole. The other light rays reflect from the cardboard surrounding the hole and bounce away. The rays that do pass through the hole continue on their way unaffected. Passing through the hole does not change them: their frequency, direction, and intensity are virtually the same as when they radiated from the sun. When these rays of light shine on a white posterboard and the light reflects from the posterboard, your eyes perceive light with all the characteristics of the sun in the sky—and you see an image of the sun.

In a sense, the hole simply reveals an image that was there all along. The image of the sun is present on the ground even when the trees are leafless and the winter sun reveals only the shadows of the bare branches. In the summer, the leaves filter out images of the sun by blocking out other images.

Tracing the paths of the light rays in Figure 3 will show you why the image is upside-down and why the image grows larger as you move the screen farther from the hole. Follow the path of a light ray radiating from the top part of the sun. After the ray passes through the hole, it keeps on going straight until it bumps into the screen and forms the bottom part of the image. Light rays from the bottom part of the sun form the top of the image.

Since the path of each light ray is straight, the rays radiating from the top part of the sun diverge from the rays radiating from the bottom part of the sun, spreading farther and farther apart. If you move the screen farther from the hole, the rays spread farther apart before they bump into the screen, making a larger image. The amount of light available to form an image is limited to the rays that pass through the hole. Since making the image larger spreads this limited amount of light over a larger area, the image becomes dimmer.

The distance between the filter and the screen is very important to the clarity of the image. How small a hole do you need to filter out an image? Practically any size will do, as long as you have a great enough distance between the filter and the screen.

To understand why, try thinking about a single square hole as a collection of tiny holes. Each of these holes creates one image of the sun in a slightly different location on the posterboard. The Image Walk demonstrates this: by covering most of the square hole with a finger and letting light pass through just one corner of the hole, you can make an image of the sun. Let light shine through another corner and there you will find another image of the sun. The square of light that forms when you hold the screen near the hole is made up of many tiny sun images.

You know that as you move the screen away from the hole, images grow larger. The images formed by light passing through two adjacent parts of the square hole grow larger as you increase the distance between the hole and the screen. As the images grow larger, they begin to overlap. As you continue to increase the distance, the images overlap more and more until they overlap almost completely. When all images formed by the light passing through each part of the hole overlap almost completely, you see a single round image. This image is fuzzy around the edges, since the images don't overlap exactly. If the square hole is ¼ inch on each side, the images will always fail to overlap by ¼ inch. If the distance between the hole and the screen is great and your sun images are large, this ¼ inch makes little difference. ○

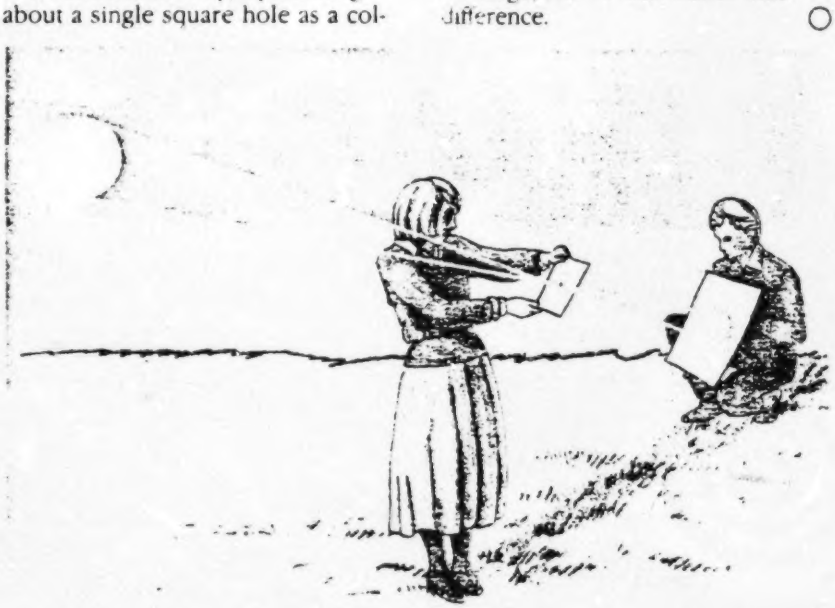


Figure 3
Only a few of the light rays radiating from each point on the sun are traveling in a direction that will let them pass through the hole. The other light rays reflect from the cardboard surrounding the hole and bounce away. The rays that do pass through the hole continue in a straight line. When these rays of light shine on a white posterboard, without the confusion created by all the other light, they make an image of the sun.

Extending the Image Walk:

Making a Pinhole Viewer

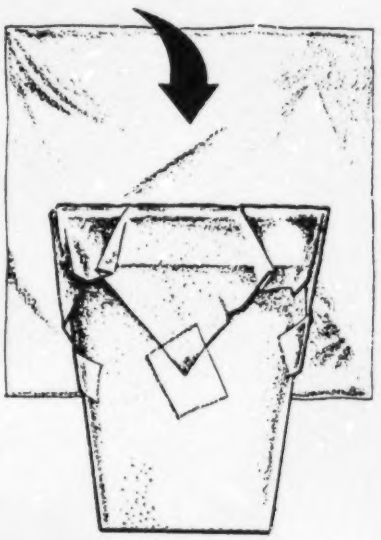
On the Image Walk, you saw that sunlight carries images of the sun. Light from other sources also carries images: candlelight carries images of the flame; light from an electric bulb carries images of the glowing filament. With a pinhole viewer, you can see these other images.

Light reflecting from objects around you carries images of those objects. Bob Miller realized this: "One thing that occurred to me when I looked at the image of the sun was: there must also be an image of the sky surrounding the sun. The light from the sky must get through the holes too. But we aren't normally aware of it, because the blue light of the sky is so dim compared to the sun. The sun is really bright—about a million times brighter than the moon. And the moon is even brighter than the clear blue sky. The reason the sun shows up so well is that the sun is so bright. But actually each hole also lets through a complete image of whatever is on the other side, including the sky, the houses, the people." Using a pinhole viewer, you can also see some of the dimmer images carried by light from sources other than the sun and by reflected light.

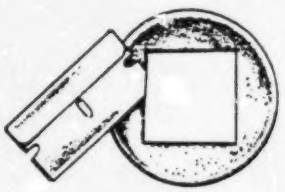
Materials:

For each viewer, you will need:
one paper or plastic cup
4" by 4" square of waxed paper
2" by 2" square of aluminum foil
scotch tape
scissors
push pin or thumbtack
candle and candle holder*
matches
exacto knife or single-edged razor blade

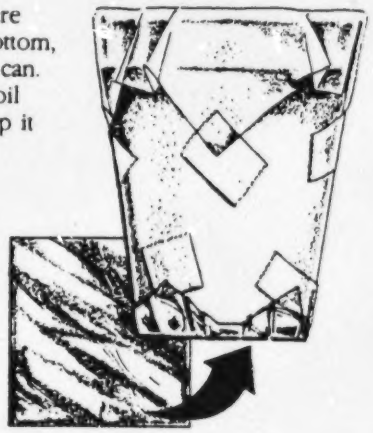
1. Tape the waxed paper over the open end of the cup, making it as flat as you can. This is the screen of the viewer.



2. Use your razor blade to cut a one-inch square out of the bottom of the cup.



3. Tape the aluminum foil square over the hole in the cup's bottom, making the foil as flat as you can. You may want to cover the foil with scotch tape to help keep it flat.



4. Use the push pin or thumbtack to punch a small hole in the center of the foil.

If your cup is not opaque, you may want to cover the sides with aluminum foil to help block light.

Using the viewer:

Put the candle in the holder, light it, and turn off the lights. The darker you can make the room, the better your images will be. With the screen of the viewer facing you, hold the pinhole about 4 inches from the candleflame. You will see an upside-down image of the flame on the waxed paper screen.

Try looking at other sources of light, such as an incandescent light bulb or a fluorescent tube. Have a friend pass his hand between you and the light source and watch what happens to the image.

Under the right conditions, you may also be able to see images carried by reflected light on the screen of your viewer. Arrange a few things on the table, shine a very bright light directly on them, darken the room, and look at the scene with the viewer. Because reflected light is much dimmer than the light from the original source, the images will be much dimmer than the image of the candleflame.

Try making other viewers with more than one hole in the aluminum foil. Each hole in the foil will give you another image on your screen. ○

*Observe the usual caution in dealing with the burning candle, a potential fire hazard. You can substitute any bright light source for the candleflame.

Extending the Image Walk:

Slide Projectors

Using a slide projector as a light source, you can duplicate many of the effects you observed on the Image Walk and extend your investigation of light and images to include lenses, a tool that you can use to manipulate images.

On the Image Walk, you used a filter and a screen to isolate the image of a light source, the sun. When you show slides, you use the same basic ingredients: a light source, a filter, and a screen. Light from the projector's light bulb passes through the slide, and the three information-carrying characteristics of the light—the frequency or color, the direction, and the intensity—change. As a result, the light carries an image of the slide. Using your slide projector, a filter, and a screen, you can isolate both the image of the slide projector's light source and the image of the slide through which the light is shining.

The instructions here are intended to help you get started in a more advanced investigation of the properties of images. The light shining from the slide projector—like the sunlight in your playground—is more interesting than you may think. Try a few simple experiments with your slide projector. You will have to play around to see some of the effects we have found and to find the methods that work best with your equipment. Don't be afraid to experiment to find the best conditions. At the Exploratorium, we have found some of the most interesting effects when we were just "tinkering around" with the slide projector and pinholes. Science involves a great deal of "tinkering around," a process integral to research and development.

You can use these activities as a class demonstration or as learning stations. ○

PREPARATIONS

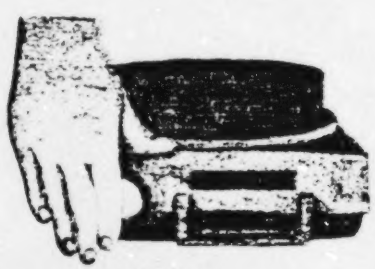
During these activities, you will see the image of the projector's light source: the filament of a light bulb. Before you start experimenting, read *Inside your slide projector* and take a look at the bulb in your projector, so that you will recognize the image of the light source.

Most slide projectors have an adjustable lens that moves in and out when you focus the image of a slide on a screen. For some of these activities, you must remove this lens from the projector. In the projectors we examined, we used the focus adjustment to move the lens as far out as possible, then pulled the lens from the projector with a gentle tug. Examine your slide projector and figure out how to remove the lens.

You will also need a 35 mm slide. Since the images you create using this slide will be somewhat blurred, the photo should show a building or a scene that is familiar, so that students will recognize a blurred image. Experiment with a few slides to find the best one. You will also need a large sheet of stiff white posterboard (measuring about 23" by 29") to use as a portable screen, a few sheets of non-corrugated cardboard (measuring about 3" by 5") to cover the projector's lens, and a thumbtack or pushpin.

Activity 1:

Set up your slide projector and insert a slide. Remember that to make the image appear on the screen right-side-up, you must insert the slide upside-down. Focus the image of the slide on a white wall or a screen placed about 7 feet from the projector. What do you suppose would happen if you blocked some of the light from the projector? Try it and see. Hold your hand or a piece of cardboard up against the lens, blocking half the light from the projector. The image on the screen dims, but remains intact. Try blocking even more of the light. As long as a little light gets through, you will see the complete image of the slide. Each little bit of the light passing through the lens carries all the information needed to make an image.

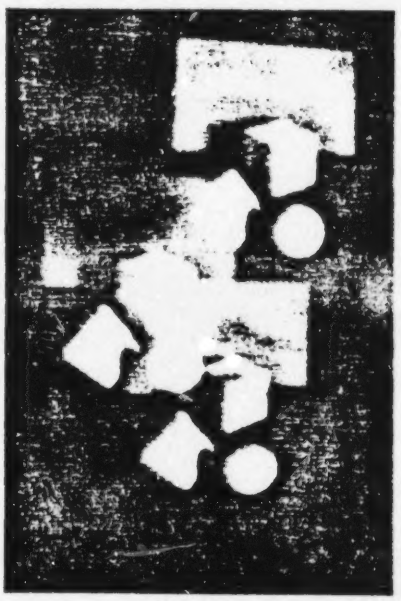


Activity 2:

Remove the adjustable lens from the projector. The image of the slide on the wall will become a blur of colored light. Use a thumbtack to punch one hole in a sheet of cardboard, then hold the cardboard over the opening from which you removed the lens. Let light from the projector shine through the hole onto your posterboard screen, held about 8 inches away. You will see a clear image of the slide on the posterboard screen. Your pinhole isolates one recognizable image.

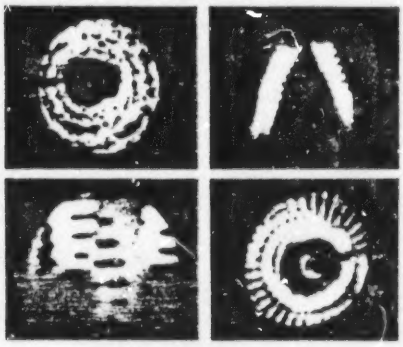
Punch one or two more holes in the cardboard. Group the holes close enough to each other so that you can position the card with all the holes over the lens opening. Within this constraint, place the holes as far apart as possible. Hold the cardboard so that the light shines through the holes onto the screen. You will have as many images on your posterboard screen as you have holes in the cardboard. Move the screen farther from the projector. The images will grow larger, but remain separate.

Replace the projector's original lens and let the light shine through the holes again. If you hold your posterboard screen about a foot from the projector, you will see one image from each hole in the cardboard. The images may overlap, but each one will be complete. As you move the screen back slowly, the images will overlap more and more. When your screen reaches the position where the image was originally focused, the images will merge to form a single image.



Activity 3:

Remove the slide. Now you can reveal the image of the light source in the same ways that you revealed the image of the slide. Hold your pinhole about a foot away from the projector so that the light shines through the hole onto the screen 7 feet away. The light shining through the hole will make an image of the light source. Use a thumbtack or pushpin to punch an array of holes in a sheet of cardboard. Space the holes about ½ inch apart. Hold the cardboard about one foot from the projector so that the light shines through the holes. The light will make an array of images—like the array on the poster accompanying this packet. Notice that each hole shows a slightly different view of the bulb.

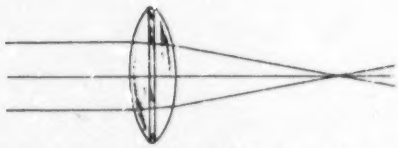


Lenses and Images

Most of the effects that you observed in this activity are very similar to the effects you observed on the Image Walk. In both you used filters to isolate an image. In both you showed that each bit of light carries an image of the light source.

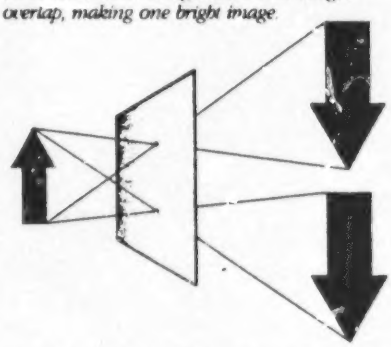
When you experimented with the slide projector, you used one tool that you did not use on the Image Walk: a lens. When you have no lens in your slide projector, the light transmitted by the slide radiates in all directions. Each part of the light carries the image of the slide, but the multitude of images overlap in a blur of light. By letting a tiny bit of light shine through a hole, you can isolate one image.

Lenses are designed to bend light. A convex (curved out) lens, like the lens in your projector, bends light rays together. When a lens bends light, it also moves the image that the light carries. By bending light rays together, a convex lens stacks many images in the same place. Because the lens overlaps many images, the picture on the screen is much brighter than the image you would see with a single pinhole.



Top: A convex (curved out) lens, like the adjustable lens in your slide projector, bends light rays together. When a lens bends light, it also moves the images that the light carries.

Bottom: In activity two, you removed the lens from your slide projector and let the light shine through two pinholes, isolating two images of the slide. If you were to put a convex lens (like the one shown above) behind the pinholes, the lens would bend the light so that the images overlap, making one bright image.



In Activity 2, you used the projector's lens to stack the images from several pinholes. When you held the posterboard screen near the projector, you could see one image from each hole. As you pulled the screen back, the images moved closer and closer together, until they overlapped completely. The lens bent the light to stack these images. When all the images overlapped completely, the slide was in focus.

You will find convex lenses in telescopes, microscopes, magnifying glasses, cameras, slide and movie projectors, and other instruments that use light to create an image.

Inside Your Slide Projector

Though each slide projector is a little different, all projectors have a few basic components. Open your projector as if you were going to change the light bulb and look for these parts:

1) the light bulb and reflector. Every projector has some light source. The bulb produces light; the reflector, located just behind the bulb, reflects light in the direction that you want it to go. In some projectors, the reflector and the bulb are one unit. In all projectors, the bulb-and-reflector combination is designed to provide a bright light. You may have to remove the bulb to take a close look at the filament, the coiled wire which glows when the bulb is on. Avoid touching the bulb with your fingers; the oil from your skin can reduce the life of the bulb.

2) heat-absorbing glass. Between the light bulb and the slide you may find a thick piece of greenish glass. This glass prevents much of the heat produced by the bulb from reaching the slide.

3) one or two condensing lenses. The projector is designed so that as much light as possible passes through the slide. The condensing lens (or lenses) catches the light from the light bulb and reflector and bends it so that it passes through the slide.

4) adjustable lens. This is the lens that you adjust to focus the slide. It catches the light that has passed through the slide and bends it to form an image of the slide on the screen.

References

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In a light-hearted style, this publication describes the seventeen exhibits in the Exploratorium's *Looking at the Light* show. The descriptions and supplementary text discuss light and shadows, pinhole images, refraction, and reflection.

• Pirenne, M.H. ***Optics, Painting, and Photography.*** Cambridge, England: Cambridge University Press, 1970.

Pirenne provides an exhaustive discussion of images and optics, recommended for the dedicated reader.

• Shull, Jim. ***The Hole Thing.*** New York: Morgan & Morgan, Inc., 1974.

You can capture the image that is revealed by a small hole on film by using a pinhole camera. Shull describes in detail how to construct and use a pinhole camera.

• Time-Life Books. ***The Camera:*** Life Library of Photography. New York: Time-Life Books, 1976.

This book about cameras and photography includes a section which contrasts the pinhole with the lens as a way of controlling light and explains the *camera obscura* in its historical context. Profusely illustrated with photos and sketches.

• Time-Life Books. ***Light and Film;*** Life Library of Photography. New York: Time-Life Books, 1976.

This richly illustrated treatise on the role of light and film in photography includes a section discussing the nature of light, with graphic representations of the electromagnetic spectrum, the effects of the Earth's atmosphere on sunlight, scattering of sunlight, reflection and refraction.

• Williamson, S.J. and Cummins, H. ***Light and Color in Nature and Art.*** New York: John Wiley and Sons, 1983.

An encyclopedic treatment of the role and behavior of light.

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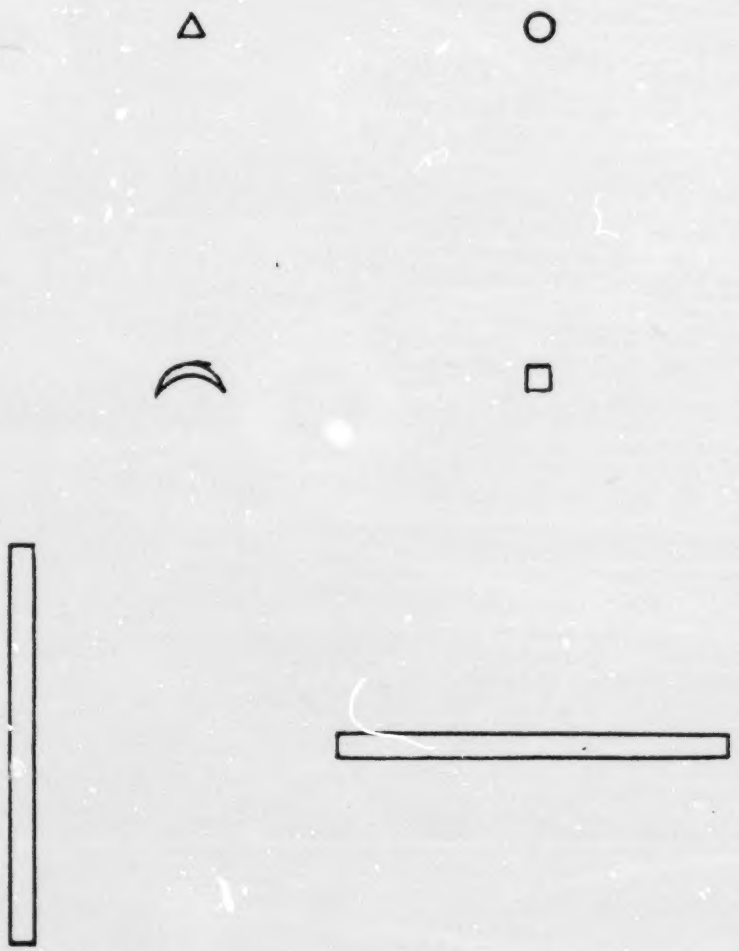
DOING SCIENCE

Spots and Streaks

Original of this card was printed on cardboard. Outlined areas indicate punch-outs needed to accomplish demonstration experiments.



The accompanying issue of *Ideas in Science* describes in detail how to do an Image Walk, a series of demonstrations that reveal the images carried by sunlight. (See page 3 for activities using this card.) You can use this card to demonstrate that sunlight passing through holes of any shape creates round spots of light—images of the sun.

You will need:
sunshine, a sheet of stiff white posterboard measuring about 23" by 29", and this card.

Tips:
Choose a patch of direct sunlight that is near a shady area. To make a round image, hold this card perpendicular to the sun's rays and hold the posterboard screen parallel to the card.

To Do and Notice:
Hold the Spots and Streaks card about a foot away from the posterboard screen and let sunlight shine through the holes. At this distance, the spots of light will be the shape of the holes in the card. Gradually move the card away from the posterboard and notice that the spots of light become more rounded. When the card is about 6 feet from the posterboard, the spots will be round. Continue to move the card away from the posterboard, and notice that the spots remain round —but get larger and larger.

Hold the Spots and Streaks card about 6 feet from the posterboard screen so that the sun shines through the rectangular holes and makes long streaks on the posterboard. Even though the ends of the rectangles are square, the streaks of light will have rounded ends. Use your fingers to divide one of the rectangles into smaller holes. Each small hole will give you a round spot. The streak of light is a collection of overlapping images of the sun, one beside the other.

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DOING SCIENCE

Reflections

Original of this card was printed on cardboard. Outlined areas indicate punch-outs needed to accomplish demonstration experiments.

The accompanying issue of *Ideas in Science* describes in detail how to do an Image Walk, a series of demonstrations that reveal the images carried by sunlight. (See page 4 for activities using this card.) You can use this card to reflect sunlight and make images of the sun. By reflecting light, you reflect the images it carries. You can also demonstrate that a large square hole acts like a collection of small holes.

You will need:

sunshine, a sheet of stiff white posterboard measuring about 23" by 29", a mirror measuring 3" by 5", and this card.

Tips:

Choose a patch of direct sunlight that is near a shady area. To make a round image, hold this card perpendicular to the sun's rays and hold the posterboard screen parallel to the card.

To Do and Notice:

Hold the Reflections card about 3 feet from the posterboard and cover most of the square hole with your finger, letting the light pass through just one corner of the hole to make a round spot on the posterboard. Move your finger to let light pass through another corner of the square hole. Light passing through the two corners makes two round images on your posterboard. Each part of the square hole lets through another round image. You could think of the square hole as a collection of lots of little holes. On the posterboard, the centers of the two images are separated by the distance between the two uncovered corners. Move the card away from the posterboard and notice that the images get larger and eventually start to overlap. If you were to move back far enough, the images would get so large that they would overlap almost completely.

Hold the Reflections card up and let sunlight shine through the holes to make round spots on the posterboard screen, held about 8 feet away. Light shining through the square holes will make round spots of light: images of the sun. Now, hold or tape a mirror to the back of the Reflections card so that each square hole will act as a square mirror. Have a helper hold the posterboard screen in a spot of shade about 20 feet from you and use the mirrors to reflect the sunlight onto the posterboard. It may take you a few tries to hit the posterboard with the spots of reflected light, but when you do, you will see that the spots of reflected light are round images of the sun. Since you have separated the card from the posterboard by a great distance, the round images are very large.

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DOING SCIENCE

Array of Holes

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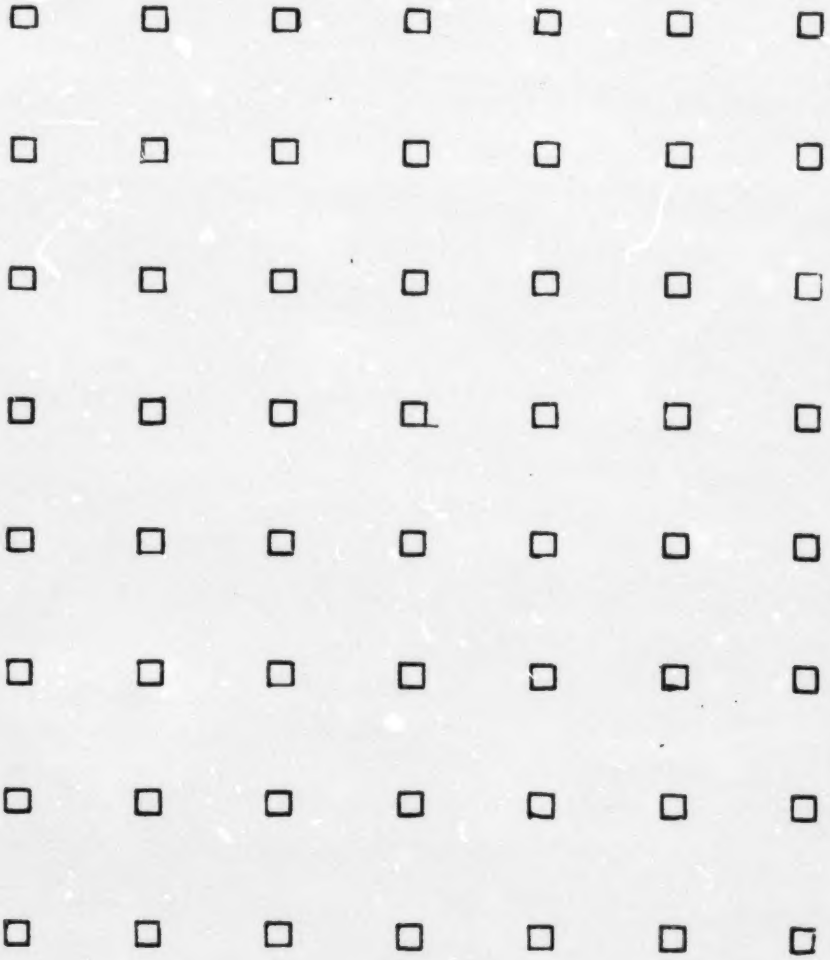

The accompanying issue of *Ideas in Science* describes in detail how to do an Image Walk, a series of demonstrations that reveal the images carried by sunlight. You can use this card to study the array of images that result from an array of holes.

You will need:
sunshine, a sheet of stiff white posterboard measuring about 23" by 29", and this card.

Tips:
Choose a patch of direct sunlight that is near a shady area. To make a round image, hold this card perpendicular to the sun's rays and hold the posterboard screen parallel to the card.

To Do and Notice:
Hold the Array of Holes card so that the sun shines through the holes onto the posterboard screen. Start with the posterboard about a foot away from the card, and slowly increase the distance between the card and the posterboard. As you increase the distance, the spots of light on the posterboard will become rounded, grow larger, and gradually begin to overlap. Each hole creates an image of the sun. If you drilled another hole in the board, it would let still another image through. You could keep drilling holes, and every time you drilled a hole you would let an image through. You could drill so many holes that you'd drill the whole board away. And then you'd have ordinary sunlight, a jumbled collection of many images of the sun.

Find the fuzzy shadow cast by something high above you, such as a tree branch or a telephone wire far overhead. Hold your Array of Holes card where part of the shadow falls across it. Hold the posterboard so that you can see the images. Notice that each image is a little different; each hole lets through a different part of the light and gives a slightly different image.

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